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Economics of Irrigation Water Management:

A Literature Survey with Focus on Partial and General Equilibrium Models

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Abstract

Water policy is an important topic on the agenda of the international community, and efficiency and equity in the allocation of water have emerged as important factors to be considered. Water pricing can be used to mitigate both the quantity and quality dimensions of water scarcity. This paper reviews partial equilibrium models and general equilibrium models that are relevant to irrigation water management issues. The most widely discussed issues in these models are water markets and water pricing. The interrelationships between economic, cultural, social, and political aspects that are related to water policy make it difficult to provide a comprehensive policy analysis. General equilibrium models of irrigation water management allow incorporation of both the irrigation sector and the other sectors in the economy and analysis of policies affecting each of them and the interaction between them. In addition to being able to address sector and household specifications, production factors, time horizon, pricing policies, and institutions such as water markets, general equilibrium models allow the analysis of the impact of water policies on equity and poverty alleviation. The authors conclude that, although there has been a significant increase in efforts to analyze water related problems, analytical and empirical research in the field is still deficient and more effort is needed to address them.

This paper—a product of the Sustainable Rural and Urban Development Team, Development Research Group—is part of a larger effort in the department to mainstream research on economics of water resources. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The authors may be contacted at dudu@metu.edu.tr and sinqochumi@yahoo.com.

ECONOMICS OF IRRIGATION WATER MANAGEMENT:
A Literature Survey with Focus on Partial and General Equilibrium Models*

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Key Words: Irrigation Management, Water Allocation, Water Pricing, Water Markets, Partial Equilibrium Models, Computable General Equilibrium Models, Water scarcity, Irrigation.

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1 Introduction

Water has officially been recognized as a scarce resource by the international community since the 1992 Dublin Statements which clearly stated that water resources are not infinite and they are “vulnerable” (WMO, 2007). The Fourth Principle of 1992 Dublin Statements defines water as an economic good. On the other hand, the first principle of 1992 Rio Statements that supplemented the Fourth Dublin Principle implicitly suggests that water is a social good, therefore humans are entitled to at least certain levels of water especially under the responsibility of their respective governments (Dinar and Saleth, 2005).

The scarcity of water has been on the agenda of policymakers and researchers in certain parts of the world, such as Middle East and Africa, for quite some time prior to the Dublin Statements. The first papers about the problems induced by water scarcity appeared as early as 1910s (Bontemps and Couture, 2002), but recognition of water scarcity as a global threat and its effects on both developing and developed countries became a widely discussed topic in the second half of 20^{th} century (e.g., Ciriacywantrup (1956, 1961); Smith (1951); Tolley and Hastings (1960)). In these early papers the central question was the allocation of water resources among different industries. Tolley and Hastings (1960), for example, follow a partial equilibrium analysis approach to determine the optimal allocation of water between energy production and irrigation. These studies do not consider any market based solution and they attempt to develop “planning routines” to allocate water in an economically efficient way.

There was a significant expansion in irrigation activities throughout the 20th century (Schoengold and Zilberman, 2005). An important part of this increase has occurred in the post-WW II period. However, expansion was especially sizable in 1980s and 1990s (Tsur, et al. 2003). Although the estimates about the growth of irrigated land for the forthcoming 30 years are moderate around a 0.4 percent per year (Tsur *et. al.*, 2003), the potential for irrigation is still enormous with increase of more than 350 percent for Africa, 150 percent for Asia, and nearly 500 percent for South America (Schoengold and Zilberman, 2005). Such a huge potential has attracted the attention of scientists from different disciplines, mainly hydrologists and economists. If water had not been scarce, this would have been “good news” for the international community. However, as the irrigated area grows, the increase in demand for water for irrigation raises more questions about efficiency, equity and justice as it is well known that water resources around the globe are limited. Since the 1980s, the need for institutions that would stimulate efficient use and equal and fair allocation of irrigation water has become a widely recognized concept by economists.

Water scarcity discussions have brought to the front deeper “issues” such as the importance of irrigation for food security and public health as well as its contribution to the development of agriculture-dependent developing economies. Irrigation consumes from 50 percent (Rosegrant *et. al.*. 2002) to 70 percent (Molle, 2002; WRI *et. al.* 2000) of global water resources. This share may even be as high as 90 percent in developing countries (Postel, 2001). In the 1990s, attempts to resolve water use and allocation issues have focused on market based solutions. Research on the topic, however, has shed light on the fact that there is no universally applicable solution to all cases, though every country, region and even basin has its special characteristics that should be taken into account while designing policies. Consequently, market based suggestions became a controversial issue. Evidence for and against market based solutions has been put forward by many researchers (Molle, 2002; Ray, 2002). There is a vast body of literature, mostly originating from economic analysis which discusses the necessity to set up an institutional framework to regulate the water markets.

The controversy about the effects of water allocation mechanisms led to the development of economic models that seek analytical answers. Most of the analysis about the effects of water allocation mechanisms either support or criticize some kinds of institutional setup, and offer new ones. However it hasn't been possible to develop a general “recipe” due to the complexity of the issue. It is difficult, if not impossible, to disseminate the results obtained from descriptive and quantitative work, especially when the researcher intends to extend the analysis beyond supply and demand analysis and make macroeconomic, social and environmental policy analysis. Partial and general equilibrium models, which explore the relationship between water policy and other economic factors explicitly, turn out to be very suitable to asses the economic and social effects of water policy. Once water is accepted as an economic good as suggested by 1992 Dublin Statements, it can be easily added to these models as a factor of production. Further, since partial and general equilibrium models allow objective oriented specification of the economic phenomena, they are also suitable to make case specific analysis without losing the generality of the same analytical framework.

The aim of this paper is to survey the literature on issues in the economics of water management, specifically in agricultural sector and to give an extended survey of the analytical tools, mainly partial and general equilibrium models developed in recent years. Surveying the irrigation water related issues through the analytical models that are specifically developed to analyze these issues originally follows from Johansson *et al* (2000). Johansson (2000) surveys the literature until 1998. Then Johansson (2005) updates the former by including the work in the area published up to 2000. In this paper, we attempt to contribute to the previous surveys in two ways. Firstly the time dimension is updated by covering work in the literature between 2000 and 2007. Secondly the computable general equilibrium models are covered in a more detailed and systematic manner.

The paper is organized in two parts. The second part aims to give a brief discussion of the issues in the economics of water allocation. In this section pricing methods and institutional frameworks are analyzed. The third section focuses on the analytical models. Partial and general equilibrium models are surveyed in detail with their structure and main findings. The last section is reserved for concluding remarks.

2 Allocation Mechanisms

Increasing scarcity of water makes the issue of efficient allocation more important. On the other hand, since water is crucial for human life, equity is also a central concern in allocation. Economic efficiency is concerned with the amount of wealth that can be generated by a given resource base. Equity on the other hand is concerned with the distribution of the total wealth among the sectors and members of society. Equity objectives are particularly concerned with fairness of allocation across economically disparate groups. Hence these two criteria may or may not be consistent (Dinar *et. al.*, 1997).

Allocation mechanisms can be defined as sets of institutions and predefined rules that determine the quantity (and sometimes the quality) of water that individual (sometimes groups of) users are entitled to use. There are three frequently used institutional settings: Markets, public administration and user based administration. Any institutional setting allocates the water through some pricing mechanism.

The allocation of water as an economic good is more complicated than the allocation of other economic goods as will be discussed in the paper, because water possesses unique characteristics that make its allocation complicated. Howe *et. al.* (1986) and Winpeeny (1994) give the criteria that should be considered for any allocation mechanism that leads to an optimal solution. These criteria are flexibility in the allocation of supplies, security of tenure for established users, real opportunity cost of providing the resource as paid by the users, predictability of the outcome of the allocation process, equity of the allocation process, political and public acceptability, efficacy so that the form of allocation changes existing undesirable situation and administrative feasibility and sustainability. The next section discusses in detail the allocation mechanisms.

2.1 Water Pricing

The theoretical foundation of water pricing is similar to that of other goods. Pricing is considered to be superior to any other method in allocating the scarce resources among competing demands (Tsur et. al., 2003). Water pricing is considered as one of the many policy interventions that can be used to mitigate both quantity and quality dimensions of water scarcity and thus enhance efficient water use. Pricing of water plays two main roles. The first one is the financial role that is a mechanism for recovering the investment and operation and maintenance cost of the water system. Secondly, it has the economic role of signaling the scarcity value and the opportunity cost of water in order to guide allocation decisions both within and across water subsectors (Dinar and Mody, 2004; Dinar and Saleth, 2005).

Economic theory explores the conditions under which pricing works efficiently as an allocation tool. When prices are set in the absence of taxes, subsidies and other distortions, the price that leads to an allocation that maximizes net benefits is called first best or Pareto efficient price. The first best allocation is attained by setting a price equal to marginal cost of the resource. When prices are set under distortions such as information asymmetry, institutional limitations or political constraints the price leading to that allocation is termed the second best efficient price (Tsur and Dinar, 1997). Pareto efficiency is regarded as “short run efficient” when the price optimization problem involves variable costs and “long run efficient” when fixed costs are included. Prices are equalized to marginal cost only under perfectly competitive markets. However it is well known that no such market exits in real life. For the specific case of water, a set of market failures exist, such as externalities (Roe and Diao, 2000), recharge, asymmetric information (Tsur, 2000), large fixed costs and declining average cost of delivery (Tsur et. al., 2003). Evidently different pricing methods will have different political, social and economic consequences. Hence the choice is not only based on efficiency criteria.

Water pricing systems have two different yet interrelated aspects. Firstly, the institutional framework under which the prices will be determined should be defined explicitly. This is because although pricing and recovery of irrigation water costs are important policy objectives, they have to be implemented within the local institutional, political and social constraints, given that higher prices can raise political tension, especially where the revenues generated are not reused for the benefit of the farmers (Dinar and Mody, 2004). Secondly the unit of price should be set. The former is likely to be determined in political processes while the latter is rather a technical question. However, overall efficiency or fairness of the pricing system will be determined by the joint effect of these two parts. Although pricing may be a useful tool, it is not always easy to implement and raising prices can sometimes have the effect of increasing overall water use. Secondly financial cost recovery for irrigation provision is gaining more widespread acceptance, though such cost recovery is not always based on economic pricing principles. (Dinar and Mody, 2004)

Pricing systems are generally classified as volumetric and non-volumetric. The former relates the price with volume of water used while the latter sets prices independent of the volume of water. Tsur *et al* (2004) provide guidelines about what to expect from various water pricing schemes for irrigation water.

2.1.1 Volumetric Pricing

In volumetric methods the price of water is set per volume of water used. Thus, this method requires measurement of water consumption. A central water agency equipped with appropriate infrastructure to set the price, to monitor the water consumption and to collect the fees is necessary for volumetric pricing. Thus, implementation costs of volumetric pricing are generally high (Johansson *et. al.*, 2002).

Marginal cost pricing is one of the most cited methods in the literature. Accordingly, the price of water is equalized to the cost of producing an extra unit of water (Tsur and Dinar, 1997). However the concept of cost is a bit ambiguous for water. In economic terms the real cost of water covers operation and maintenance costs, capital costs, opportunity costs, costs of economic and environmental externalities. *Supply cost* includes the first two of these. Supply cost together with economic externalities and opportunity costs constitute the *economic cost*. Lastly economic costs and environmental externalities add up to *full cost* (Rogers *et. al.*, 2002). In most cases, only supply costs are taken into account in pricing. However, the other cost components are much higher than the supply cost (Rogers *et. al.*. 1998; Johansson *et. al.*, 2002). Limiting the pricing merely to supply cost is partly due to the difficulty in measuring other cost components and partly because of the political choices.

In the absence of implementation costs, i.e. full cost equals to supply cost; marginal cost pricing is optimal in terms of efficiency. However, when this assumption is not satisfied it is obvious that marginal cost pricing will not be able to attain first best solution and thus the price level obtained by ignoring the other cost components may not yield efficient allocation of water (Rogers *et. al.,* 1998; Tsur and Dinar, 1997). Thus a two part tariff pricing which would be composed of by a fixed admission fee and the marginal cost of supply can at least converge to an efficient allocation. Here the fixed amount can be considered as a compensation for the unobserved cost components. Further, for irrigation projects for which the marginal supply cost is below the average supply cost at the produced level of water, fixed part of tariff compensate the difference between marginal and average cost.

Marginal cost pricing can be criticized for not taking equity concerns into account. A more equitable pricing system can be obtained by introducing a tiered pricing or two-part tariff. In tiered pricing different prices are set for different consumption levels. The charged price increases as the consumption increases. In this way different income groups can be addressed with different prices. However, it is obvious that this benefit comes at the cost of complicating the implementation costs (Johansson *et. al.*, 2002).

Bar-Shira *et. al.* (2000) estimated farmers' demand for irrigation water in 185 Israel agricultural communities under increasing block-rate tariffs and empirically assessed its effect on aggregate demand and inter-farm allocation efficiency. Block rate pricing is different form marginal cost pricing in that it tries to induce water use reduction without burdening farmers with the full cost that simple marginal cost pricing would entail. In contrast, an increasing price schedule allows imposing the high, socially optimal price at the margin while maintaining a lower average price, thus keeping small farms in business. They found that, switching from a single to a block price regime yielded a 7% reduction in average water use while maintaining the same average price. Based on their simulations they estimated that the switch to block prices would result in a loss of approximately 1% of agricultural output due to inter-farm allocation inefficiencies.

Brill et al (1997) in their case study of Hasharon region in Israel compared different policy options to allocate water in response to a reduced supply. Among their conclusions are that, average cost pricing with quota reductions results in administratively inefficient pricing and allocation, water markets cannot be remedy in the absence of well defined property rights and the solutions to the problem are hindered by high transaction costs. Tiered prices, on the other hand, lead to a 'second best solution' while passive trading would lead to Pareto efficient allocations.

2.1.2 Non-Volumetric Pricing

An important deficiency of volumetric pricing is the difficulty of monitoring the actual amount of water consumed. This difficulty can be overcome only by implementation of measurement accessories such as water meters. However installation and maintenance of these accessories are relatively expensive and can be economically infeasible for most cases. Bos and Walters (1990) state that an important proportion of farmers throughout the world operate under non-volumetric pricing (Johansson, 2002).

Most common non-volumetric method of pricing is per area pricing (Bos and Walters, 1990). In per area pricing, users are charged according to the area irrigated. Charged price generally depends on the crop choice, season and irrigation method (Johansson, 2002). This method is easy to implement and administer (Tsur and Dinar, 1997). The method only requires collection of data about the farm size and crop choice which is likely to be available in most cases. Since per area prices are fixed costs for farmers, it is not likely to determine effectively the amount of water demanded. This is likely to bring about an inefficient allocation of water. On the other hand per area pricing will affect the crop choice of farmers given that price changes according to crop choice.

Another group of non-volumetric pricing method is input or output based methods. These methods adapt a more indirect approach to measure the water consumption and are used when water consumption information is unavailable, unreliable or very expensive to collect. In input based methods water related inputs are taxed. Output based methods charges water fees per output produced. These methods can attain only a second best allocation since *"… the output fee and the zero price of water will distort decisions regarding input and output away from the first-best outcome achieved under the marginal pricing rule. The presence of implementation costs constitutes another source of deviation from a first-best allocation"* (Tsur and Dinar, 1997:259). Deviation of these methods from efficient allocation depends on the implementation costs (Tsur and Dinar, 1997) and relationship between water consumption and production, i.e. productivity of water. If water productivity is high then these methods will attain a solution closer to first best allocation while if it is low, since output produced or inputs used will be a bad proxy of water consumption, they will deviate from efficient allocation more.

In the absence of implementation costs non-volumetric pricing will almost always be inferior to volumetric pricing since the former will result in a second best solution while the latter will reach a first best allocation. However implementation prevents volumetric pricing to achieve a first best allocation. Thus, depending on the case specific factors, non-volumetric methods may produce higher welfare compared to volumetric methods.

There is a vast of literature analyzing the effects of implementing water pricing methods to ration water. For most countries these policies have failed to perform well, mostly due to faulty approaches and inappropriate institutions that have their roots in complicated political and economic environments (Dinar and Saleth, 2005). Ray (2002) got evidence from a study of the Mula Canal in India that farmers do respond to price induced water scarcity but water price policy and/or a system of tradable water rights are not the most effective ways to increase irrigation efficiencies. Maskey and Weber (1998) form a field study in Nepal on the possibility of introducing cost recovery irrigation fees. They concluded that farmers under both government- and self-run irrigation systems are in a position to pay the Operation and Maintenance (O&M) cost. However, charging capital as well as O&M costs is found to be difficult to justify. These conclusions were made from both a comparative analysis and the marginal value product (MVP) approach.

Ortega et al (1998) simulated the behaviors of farmers and their response to different water pricing scenarios on water demand, farmers' income and the revenue collected by the government agency. This was done for irrigation districts in Spain. Results showed that the effects of alternative pricing policies for irrigation water are strongly dependent on regional, structural and institutional conditions and that changing policies produce distinct consequences within the same region and water district. Thus, equivalent water charges would create widespread effects on water savings, farm income and collected government revenue across regions and districts.

Latinopoulos (2005) considers different case studies of irrigated agriculture in Greece as they relate to water management. The study applied a Contingent Valuation Method and a Hedonic pricing method in an effort to find the value of irrigation water. The study draws the conclusions that the value of irrigation water as estimated by the water users is low because it relates to its use component. From the case studies it has also been concluded that the application of the principle of full cost recovery produces negative social impacts, it is also not an efficient management tool when implemented on its own.

2.2 Institutional Frameworks

The effects of different pricing methods cannot be considered independently from the institutional setup. The feasibility and efficiency of a pricing method can vary greatly from one case to another. The institutional framework determines the rules and regulations that economics agents are subject to. In other words, the institutional framework determines the constraints that the economic agents should take into consideration. Hence the issues about pricing methods –in fact any water related issue – cannot be understood without a proper description of institutional framework. In this section we will briefly discuss the institutional setup that relates to irrigation water management.

2.2.1 Water Markets

Markets are considered to be the most efficient way of allocating scarce resources by economic theory (Coarse, 1960). However this conclusion depends on restrictive assumptions. Economic theory legitimizes the public intervention to the allocation of resources in cases where the competitive markets cannot function. The failure of markets is a well-known fact in economic theory (Bator, 1958; Randall, 1983). Many different aspects of these failures are analyzed by various researchers (Stiglitz, 2002). Public good nature of water, implementation costs of large irrigation projects, incomplete information about the scarcity and availability, externalities, scarcity, returns to scale, equity concerns are among the most important reasons of market failures. (Johansson, 2000)

Provision of goods and services can be characterized by the excludability and subtractability (Easter, 1997). Excludability implies the possibility of excluding specific agents from consuming the good while subtractability refers to the fact that consumption of the good or service by one agent leads to subtractions from the consumptions of other agents. Though water is both excludable and subtractable good, provision of services are not always so. Especially large irrigation projects that cover large number of farm plots, exclusion is quite difficult and once the irrigation infrastructure is built the service is enjoyed by all agents in the region without causing any subtraction. Thus, an important caveat about the public good nature of the water is that, the right to use is not directly related to water but rather to the provision of water. However these two properties about the infrastructure cause an important problem directly in the consumption of water. Although irrigation services are not subtractable, water itself is. Amount of water used effects the supply for the others users (Livingston, 1993). Overuse of public goods due to the ignorance of the users about the others’ interest in the pursuit their self-interest is a well-known fact in economics (Hardin, 1968). Accordingly, overuse of public goods makes the sustainability of the public good impossible. The very same problem is observed in the case of water. The public good nature of irrigation infrastructure causes markets to fail to provide irrigation services. Public control is among the most popular solutions to the problem. However, coverage of the “public” concept is rather case specific. It refers to government in some cases and to some kind of user associations for others (Schoengold and Zilberman, 2005).

Failure of markets in provision of irrigation services can also be due to high implementation costs of large irrigation projects. The costs are not only limited to the building costs but also includes political, physical and institutional environment (Tsur *et.al.,* 2003). In most cases irrigation infrastructure is not economically feasible for the private sector. Public provision is among the most mentioned solutions. Tsur (2000) gives a detailed analysis of the effect of implementation cost on efficiency.

Incomplete information about the scarcity and availability of water is another underlying problem. Asymmetric information is also an important reason of market failure. Asymmetric information comes on the scene in various ways. Most prominent reasons of asymmetric information are due to the nature of supply of water. Water users do not have exact information about the quality, quantity and timing of supply, since supply of water is determined by climatic conditions. Further, water exists in “discrete chunks” and is “naturally concentrated” in common pools or streams. That is to say the transportation or in general the implementation problems “naturally” exist in the case of water markets. Lastly, the consumption of water is not mutually exclusive among users. Amount of water used effects the supply for the others users (Livingston, 1993). Tsur (2000) offers an output based pricing to overcome the difficulties of asymmetric information. A more general analysis of regulation under asymmetric information can be found in Laffont and Tirole (2003) (Johansson, 2002).

Another underlying reason of market failure in the provision of water is the existence of negative and positive externalities. Externality is a cost or benefit due to an economic activity which is enjoyed (for positive externalities) or paid (for negative externalities) by the third parties. A good of which consumption by an economic agent brings about externalities for the other agents can be allocated efficiently in a market, if and only if the externalities are priced appropriately. However, a competitive market without the existence of public intervention is incapable of pricing these externalities.

Water production technologies bring about increasing returns to scale since per unit cost of water provision is inversely related to the amount of water used. Consequently marginal cost of production will always be less than the average cost and the supplier will have an incentive to supply more water. Increasing returns cause the emergence of natural monopolies and hinders the market mechanism.

As mentioned above water supply is determined by the nature and it fluctuates according to the climatic conditions. Under scarcity the defined water rights will not be tradable since they will not represent anything at all. Thus, supply side problems can prevent competitive markets to operate.

Another impediment of water markets is the concerns about equity in the allocation of water. In other words, the social cost of efficient allocation is not taken into account by the market mechanisms. Equity concerns can be formulated by the effect of water allocation mechanisms on the income distribution. Tsur and Dinar (1995) argue that most pricing mechanisms have little effect on income distribution. Another aspect of equity discussions relates to the internalization of externalities. For example, irrigation is likely to bring about lower food prices by increasing productivity of other production factors such as water. These low food prices are enjoyed by the rest of the economy. However markets do not take this externality into account. Equity concerns however, require that this externality is priced appropriately by the market mechanisms.

Lastly any market mechanism to allocate water needs some kind of central agency. Such organizations generally cause inefficiency per se due to the problem of "political economy of neglect" which states that "… if agencies who fail to provide the necessary upkeep to their irrigation system are bailed out by a donor agency, there will be a lower incentive for them to provide efficient levels of maintenance." (Schoengold and Zilberman, 2005:20).

In evaluating different sets institutional arrangements, market pricing in the absence of impediments constitutes a benchmark. Any market solution to the water pricing problem deviates from market solutions with the introduction of externalities, both positive and negative, transportation costs and difficulties in defining the entitlement rights. In such cases central regulation and government intervention is inevitable (Easter *et. al.*, 1997).

The options for the systems of water management are only limited by the diversity of irrigation systems. The key characteristics of these systems are imposed by the managerial responsibilities, exercised control over water allocation, and the locus of the organizational control (i.e. top-down or down-top control) as well as the agents involved in irrigation. Managerial responsibilities of the system bring about considerable benefits by sustaining coordination of demand and supply while it requires substantial costs for information collecting and processing activities. System control is important to assure that rules of allocation are not violated by the agents. However, adequate control end in significant costs spent in monitoring and enforcement processes. Agents involved in the allocation system can be farmers, managers and government agencies. The involvement of these agents is likely to determine the extent which the system deviates from the competitive market benchmark. Too much involvement by government is likely to increase the inefficiency, while too little of it makes the system vulnerable to the market failures (Roumasset, 1997).

Water markets critically depend on three pillars: Well defined property rights (Curie, 1985), public information of supply and demand (Curie, 1985; Tsur, 2000) and physical possibility of trade (Roumasset, 1997).

In practice the subject of trade is water rights (Roumasset, 1997). Operation of water markets, thus, critically depends on the definition of ownership rights (Schoengold and Zilberman, 2005). The structure of these rights is the driving force of the incentives and disincentives that make the market operational.

The value of water should be separable from the value of other goods or assets such as land (Lee and Jouravlev, 1998). Among many others Curie (1985) defines the necessary conditions for a market to operate as well defined property rights, public information on the supply and demand and physical possibility of trade. Johansson (2000) extends this list in accordance with the special characteristics of water. In most parts of the world water rights are embedded in the land rights and the existence of a water market requires separation of these two rights (Roumasset, 1997).

A management organization is also necessary to implement the transactions while the existence of infrastructure to transfer the water itself is also critical. This necessity implies some kind of public intervention in the market system. The size of investment necessary to allocate water and complex issue of the measurement of its usage make the establishment of a managing organization inevitable (Johansson, 2003).

The allocation system should allow internalization of externalities. Otherwise a market system will operate inefficiently (Coarse, 1960). Internalization of externalities is generally attained by markets under full information. Thus a central agency that will enforce this internalization is important for efficient operation of market system.

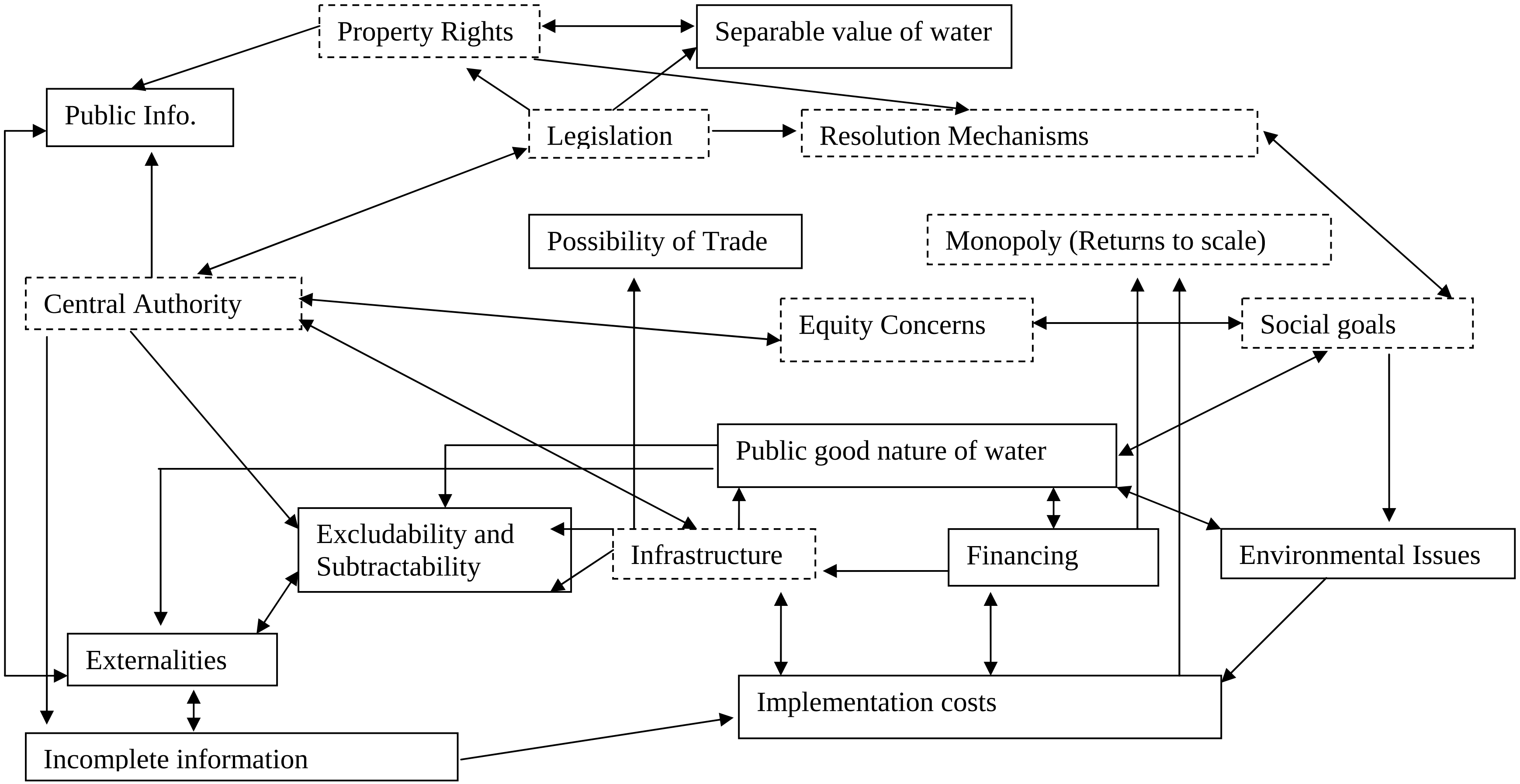


Figure 1: Essential relationships between different factors concerning water markets.

Effective resolution mechanisms are necessary to solve the conflicts between water rights and equity concerns such as social goals (Roumasset, 1997; Johansson, 2003). These mechanisms generally consist of well-defined water rights by legislative bodies and well-established social goals by political processes.

Public information of supply and demand is another important issue in efficient operation of water markets. Tsur (2000) shows that in the absence of symmetric information, efficient allocation of water may not be attained by competitive markets.

Lastly, physical possibility of trade is in the core of all. Transfer of water from some region to other requires appropriate infrastructure. Most of the time, the establishment of this infrastructure needs extensive investments which require enormous financial resources.

It is easy to follow the fact that components that are required to operate water markets efficiently are not independent. A setting that cures an obstacle can be the cause of another one. Figure 1, shows the essential relationships between different factors that affect efficiency of market system.

There have been a number of attempts in the literature to study on the applicability of water markets. In an attempt to examine the potential benefits of water markets as policy tool for addressing water quality problems of irrigated agriculture, Weinberg et al (1993) in their study on California concluded a 30 percent drainage reduction goal is achievable within a water market. There is potential therefore for a water transfer that could benefit both agriculture and urban sectors. Armitage *et al* (1999) surveyed how the establishment of tradable water rights in two irrigation districts in South Africa could be of benefit to society. The first area was the Lower Orange river where water is so scarce that production depends entirely on irrigation. It was seen that water rights moved to farmers who have achieved the highest estimated return per unit of water applied. The second observation was that water rights moved from potentially lower valued users with the potential to grow wine grapes and raisin grapes, to potentially higher valued users with the potential to grow table grapes. Buyers had larger amounts of undeveloped arable land, highlighting the efficiency advantage of market trades of bringing undeveloped arable land into production. The second area was the Nkwaleni valley where water is also scarce with production depending entirely on irrigation but there has been no trading of water rights. It was observed that there were no willing sellers of water rights. This may attributed to the fact that surveyed farmers in the Nkwaleni Valley were generally found to be using their full water-rights allocation in their farming operations, and capital investment in irrigated land may have inhibited the sale of water rights from this land. Irrigators may also have preferred to retain excess water for water supply security.

Gardner et al (1968) studied irrigation water transfer in an area in Utah. The transfer policy and the water supply were the explanatory variables that accounted for most of the variation in the rental price of water. Making water available for rent was an important factor in reducing an important area of risk by inducing farmers to alter their cropping patterns. The efficient farmers could potentially produce high value, high water using crops, others would save it in order to rent it out. Statistically significant differences between the predicted rental prices under different allocative policies provided strong evidence that transfer freedom is very important to efficient allocation of resources. Backeberg (2006) evaluated the changes that have occurred in South Africa pertaining to user charges for cost recovery; market pricing, enabling market trades for water reallocation, and the process for transformation of WUAs. The conclusions pertaining to water markets were that water licenses were considered to be insecure.

2.2.2 Public Administration

Public administration is prevalent in large scale irrigation (Schoengold and Zilberman, 2005). Deficiencies in water markets call for public intervention. In the ideal case, public administration of water resources seeks to optimize social welfare by taking into account the market failure. Other water services are characterized by economies of scale, such as the large role of the public sector in its development and management being more essential than it is for other goods that can be handled efficiently in a market framework (Dinar *et. al.*, 1997). Some water services are public goods, that is, their provision to one individual does not eliminate other individuals from using it. Non-excludability could then result in under-investment, mis-allocation of the resource, and negative externality effects among the potential users, leading irrigation projects whereby, the average cost decreases as more units are produced. This may create monopolistic power and socially inefficient allocation, leading to market failures.

Water projects are usually associated with large investment; most capital markets do not have the capacity to finance such huge investments over the necessary time period. Because of the range of market failures and the large volume of capital needed for water projects, a significant share of water-related infrastructure investments is conducted by the public sector. Therefore the need for huge funding which can be covered in very long run, as well as underdeveloped financial institutions, and possibility of political intervention makes these investments undesirable for private sector.

Public administration may be needed to regulate the consumption to achieve socially optimal allocation when the consumption of a user adversely effects the consumption of others (negative externality). Public administration can ensure that required investments are made to avoid specific problems such as infrastructures to prevent floods, storage facilities that will be used in times of scarcity or that will maintain quality of water.

Lastly, water is a strategic resource in sustaining life and it is important for national security and regional development. Thus protection of water resources is a public good which calls for involvement of government (World Bank, 1993). Public administration is thus desirable especially in some specific cases.

Thus public administration of water resources can meet the conditions for *"equity, sovereignty, and an overwhelming concern with satisfying the water itself and water services as public good. Ideally, these objectives and the efficiency objectives produced by marginal cost pricing would be met simultaneously"*. (Dinar *et. al.*. 1997:10)

Along with these virtues, public administration has well-known deficiencies (Dinar *et. al.*. 1997; Schoengold and Zilberman, 2005; Spiller and Savedoff, 1999). Firstly government financing of irrigation services disrupts the relationship between price and cost. That is to say, water is not priced on the basis of its marginal cost, which in turn causes inefficient allocation. Spiller and Savedoff (1999) call this fact as "government opportunism", and points out the fact that government can keep prices lower or subsidies higher than the socially optimal level to keep their citizens happy (Schoengold and Zilberman, 2005). Secondly, inefficiency of publicly administrated irrigation systems is a common observation (Tsur *et. al.*, 2003; Çakmak, 2003; Dinar, *et. al.*, 1997, Schoengold and Zilberman, 2005). Meinzen-Dick *et. al.*, (1996) argue that an underlying reason for such failures is the lack of incentives for conservation and efficient use of water under public administration (Dinar *et. al.*, 1997). Furthermore, Schoengold and Zilberman (2005) show that public administration may end up over-investing in new infrastructure and neglecting the maintenance of old ones. This fact can be explained by the theory of "political economy of neglect" (Schoengold and Zilberman, 2005).

Lastly, Yoder (1980) draws attention to the fact that most of the water management agencies have local or sectoral responsibilities which brings about ignorance about the general state of water resources. Consequently, these agencies lack the incentive for developing integrated projects (Dinar *et. al.* 1997).

2.2.3 User Based Administration

User based administration (or Water User Associations - WUA) lies somewhere in between a market system and a public administration. WUAs have become more and more prevalent in the last two decades (Dinar et. al.. 1997, Schoengold and Zilberman, 2005). A WUA is an administrative body formed by the beneficiaries of the water resources. This body can be formed in many different ways. Government officials may or may not be represented in the management board. It can be sector based or region based. It can be formed by the beneficiaries from a single sector or from various sectors. It may or may not be controlled by some superior official or unofficial central agency. Beneficiaries can be represented directly or indirectly. The association can be a monopolist, oligopolist or just one of the many suppliers. The body may aim to maximize its profits or it can be a non-profit organization.

Coward (1986) states that effectiveness of WUAs is crucially dependent on well defined user rights which constitute the basis of relationships between users (Dinar *et. al.,* 1997). Collective actions among users are, thus, impossible without the existence of property rights on water. Many case studies show that WUAs operate more efficiently (Schoengold and Zilberman, 2005). Easter (2000), further they argue that when WUAs are required to purchase the water they use, this gives them an incentive to conserve and use water efficiently (Schoengold and Zilberman, 2005). Meinzen-Dick (1997) states that long term farmer participation is the key success indicator for WUAs (Johansson *et. al.*, 2002)

WUAs have many advantages over pure market or public administration systems. First of all, they are more flexible since the rules of allocation and pricing are set by the users themselves. Thus, WUAs can rapidly adapt their rules when conditions change. This flexibility follows not only from ability to adjust rules but also from being local institutions. They have more information about the local conditions. (Dinar, *et. al.*, 1997). Further locality enables more successful resolution of conflicts among members (Dinar *et. al.*. 1997). WUAs are more successful in increasing water supply (Dinar, 1997) and maintenance investments (Kloezen *et. al.* (1997) cited in Johansson, 2002), since the members of WUAs directly benefit from these activities. Further, WUAs bear lesser costs in gathering information on local resources. WUAs have administrative feasibility, sustainability and political acceptability. Easter and Welsch (1986) and Wade (1987) state that WUAs decrease the implementation costs significantly (Johansson et. al., 2002).

WUAs may also have important disadvantages. Ruttan (1998) states that institutional design is problematic (Johansson et. al., 2002). Besides, conservation depends on consciousness of board members and beneficiaries. Another problem is the necessity of a transparent institutional structure, which may not always be available. Further, local user-based institutions can be limited in their effectiveness for inter-sectoral allocation of water because they do not include all sectors of users (Dinar et. al.. 1997). Lastly, WUAs may fail to sustain equity (Dinar et. al.. 1997). Dayton and Johnston, 2000 show that WUAs may not be equitable since wealthier landholders are able to push for a higher share of total water. Thus, some level of equality in land-holdings is necessary for the success of WUA based management (Schoengold and Zilberman, 2005).

2.3 Irrigation and Poverty

Equity considerations in the allocation of water in agriculture have led to the development of literature on the impacts of water allocation on poverty alleviation. Poverty is an outcome of complex interactions of resources such as land and water that poor people largely depend on, compared to the non-poor and other resources, institutions, actions and policies and their ultimate outcome. Poverty is a multidimensional concept that by definition extends from low levels of income and consumption to lack of education and poor health. It also covers social aspects such as hopelessness, uncertainty, susceptibility, isolation, and gender disparities. The basic needs vary across time and space; therefore poverty lines also vary depending upon the level of socio-economic development, social norms and values within regions in a country or across countries (Hussain *et. al.*, 2006).

Recent studies on poverty and irrigation make a distinction between different forms of poverty. They distinguish between chronic or permanent poverty and transient or temporary poverty. Chronic poverty is associated with lack of assets (both physical and human), low level of productivity, disadvantageous demographic characteristics (such as large families and high dependency ratios), and location in more remote and backward areas. Transient poverty, which is also related to lack of assets, is more typically associated with households' inability to insure themselves against fluctuations due to either external factors such as price levels, climate change or job availability or household-level shocks such as serious illness or death of family members (Hussain, 2007).

It would be naive to perceive that all rural poverty problems could be solved through improving the poor's access to water alone. Water is one of the most important factors in poverty equation with its wide effects. (Husain and Hanjira, 2003). Irrigation has been proven to be a poverty reduction tool for the 21St Century. This is supported by the fact that greatest reduction in poverty has occurred in the regions that have had the greatest proportion of irrigated land. There are evidences from East Asia, Pacific, North Africa, and Middle East. This is in contrast to Africa where only around 3% of cropland is irrigated and the region has experienced very little reduction in poverty in the 1990s (Lipton *et. al.*, 2003). As a production input in agriculture, irrigation water is an important socio-economic ‘‘good’’, with a positive role in poverty alleviation but it can also become a socio-economic ‘‘bad’’ when it leads to problems such as waterborne diseases (malaria, schistosomiasis), and land degradation including water-logging and salinity, water pollution and associated destruction of living beings and natural ecosystems, i.e. negative externalities associated with irrigation (Hussain and Hanjra, 2004).

Table 1 : Poverty Incidence and irrigation in developing regions.

$1–a–day poverty (1998)				
	Incidence (millions)	Total Population (%)	Change in Incidence 1997-98 (%)	% Irrigated area per ha cultivated area(arable+ permanent cropland) 1999
East Asia and Pacific	278	15	-33	20
Latin America h Asia	78	16	22	12
Sub-Saharan Africa and the Caribbean	5	0.04	-44	27
North Africa and the middle East	522	39	10	6
Sub –Saharan Africa	291	44	34	3

Source: Poverty figures from World Bank (2000, 2001), Irrigated land from FAO Statistical Database

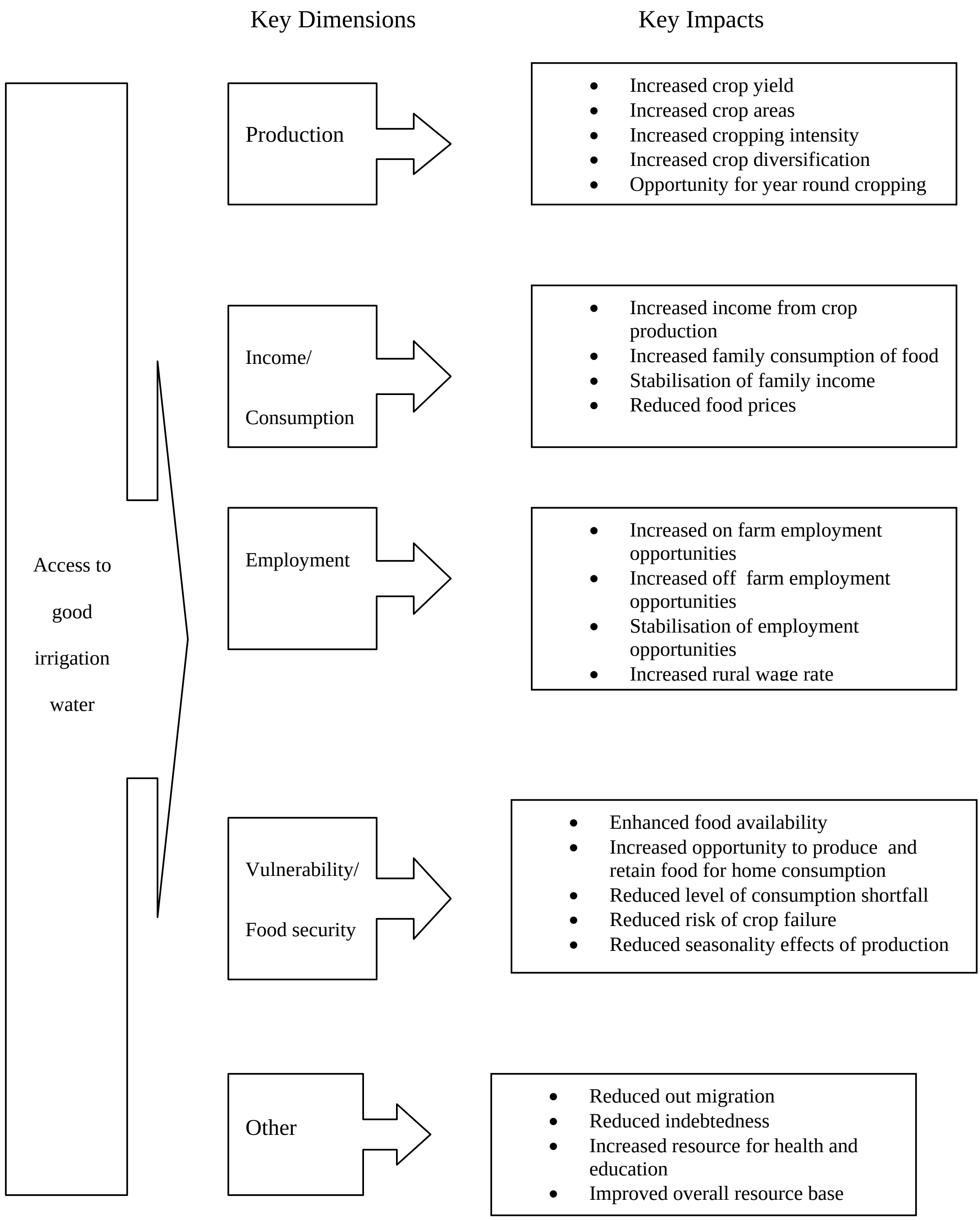
Lipton et al (2003), Hussain and Hanjia (2003) and Hussain and Hanjra (2004) laid out a conceptual framework for analyzing the transmission mechanism between irrigation and poverty. Irrigation has direct impacts on poverty via increases in output levels and employment and further second round effects on poverty via output, employment and prices. Irrigated land usually encourages farmers to adopt or increase their use of fertilizers, pesticides, improved seeds and other agricultural inputs and provides the stimulus for further research into improved plants and technology that lead to increased output, employment and incomes with possible further reductions in prices. The longer run effects on poverty are also via non-farm rural output and employment through expenditures on non-food products and services. Irrigation also has socio-economic impacts as negative health effects associated with increase in the incidence of water related diseases such as schistomiasis and malaria, displacement of large numbers of people and negative environmental effects of dam construction. Positive effects could be in the form of improved nutritional outcomes through the availability of increased and more stable food supplies and sometimes-cleaner water.

Three pathways have also been identified in the literature as the mechanisms through which the poverty reducing impacts of irrigation follow. Firstly it is the micro-pathway which manifests itself through increasing returns to physical, human and social capital of the poor households (productivity pathway). Secondly there is the meso-pathway which operates through integrating the poor into factor-product and knowledge/information markets (market participation pathway). Thirdly, there is the macro-pathway which works through improving national growth rates and creating second-generation positive externalities (economic growth pathway) (Hussain and Hanjra, 2003)). These three pathways are interlinked in their functions.

Using evidence from the Uda Walawe Left Bank Irrigation Scheme (WLB) in Sri Lanka, Hussain and Hanjra (2003) concluded that irrigation water does matter for poverty alleviation, unequal land distribution is associated with inequitable distribution of agricultural –water benefits , benefits of irrigation and its antipoverty impact are greatest in settings with low land inequality, rural poverty alleviation requires that agricultural/water irrigation development be targeted at poor communities/areas/localities and that effective poverty alleviation in irrigated agriculture also necessitates broad and targeted interventions in both hardware and software dimensions that entails building partnerships between actors and stakeholders.

Vaughan (1997) studied the potential of irrigation development in South Africa in having positive impacts on rural poverty. The paper concluded that although irrigation development had been a mechanism that was historically used by the apartheid state to realize its political and economic agendas, it offered a range of possibilities for poverty alleviation. The paper recommended that clear policy principles were essential along with relevant information to guide the provincial departments of agriculture and the local authorities.

Figure 2 : Irrigation water and Poverty linkages



Source: Based on Hussain and Hanjra (2003).

Letsoalo *et al.* (2005) in their study sought ways of reducing poverty in South Africa while at the same time implementing policies that address water scarcity problems The results of the study showed varied impacts of these policies on poverty.

Hussain *et al.* (2006) using cases of areas in Pakistan concluded that access to irrigation through small-scale irrigation schemes must be encouraged to increase crop production in order to alleviate poverty.

Huang *et al.* (2005) on the study of irrigation and poverty in China found evidence that irrigation has a strong impact on income and poverty. They also found that irrigation helps to reduce income inequality. Irrigation investment in rural China appears to be an investment that can lead to both growth and equity in some provinces.

3 Water in Economics: Quantitative Models

Models form the core of analytical tools in economics. Verbal, graphical, mathematical or computational methods are used to formulate conceptual simplifications of real life phenomena (Howitt, 2005). These simplifications help the researcher to avoid unnecessary complications of real life that are out of the scope of research and focus on the aspects that are of the interest.

The same approach is followed in the literature for the economic analysis of water allocation. For this purpose mainly two families of economic models can be used: Partial and general equilibrium models. As the name suggests, both approaches depend on the assumption of equilibrium and the difference between them is the level of assumed equilibrium. Partial equilibrium models consider the effects of water policy on a specific market, by ignoring the linkages between whole economy and that specific sector. This assumption is viable if the market under investigation is relatively small. For example a water market can be analyzed by partial equilibrium analysis, especially at basin level since effects of changes at basin level will have limited effect on the whole economy. On the other hand, general equilibrium models may be more suitable to analyze the effects of different pricing schemes on income distribution among different social groups.

Both partial and general equilibrium models can be formulated by different analytical tools. Algebraic expression of a model is just one of these tools among others. Further, different analytical tools are used simultaneously to formulate the model more precisely. Howitt (2005) defines analytical tools that are used simultaneously in the modern neoclassical modeling. Firstly, simple verbal models are used to define the qualitative properties of a paradigm. A simple verbal expression is a necessary condition in understanding the complex structures of mathematical models. Secondly graphical models are extensively used in the literature to introduce the relationships between functions and equilibriums. Although graphical models are generally limited to two or three dimensions they are very useful in formulating the relationships between different variables. Lastly, algebraic methods are used to extend the analysis to multi-dimension cases. In economic literature, models are generally identified with algebraic models for the last 5 decades (Howitt, 2005).

Algebraic models are the main tools that economists use in analyzing the issues discussed in previous sections. Pricing methods and institutional framework determines the structure of the economic models related to the irrigation water management. In this section we will survey algebraic economic models designed to analyze the water policy with special emphasis on general equilibrium models.[2]

3.1 Partial Equilibrium Models

Partial equilibrium models are of special interest to the researchers of irrigation water management, since for most cases water constitutes a small part of agricultural input markets due to lack of appropriate pricing and institutional setup. Hence by using partial equilibrium models, one can make inference about the possible outcomes of different institutional setups and pricing strategies. In this section we will survey the partial equilibrium models developed to analyze irrigation water management related issues.

3.1.1 Background

The focus of partial equilibrium models is on the equilibrium conditions of a market for one good/sector which is a part of the overall economy. By doing so, partial equilibrium models assume that the prices are fixed in the other markets. Marshall (1920) emphasize that when the share of the good under study is a small proportion of consumer's total budget, income effects will be minimized which implies that the market under study can be assumed to be independent from the macroeconomic relationships that affect the whole economy. Secondly, interaction between prices of different goods can also be assumed to be minimal. Under these

[2] There are also models that attempt to figure out the optimal water allocation. An example of such models is Ghahraman.and Sepaskhah (2004) where authors use water production functions to model the relationship between irrigation and yield. They optimize "irrigation water allocation for single- and multi-cropping patterns in a field". However, the model does not have an economic module that relates allocation to prices. Another example is Smout and Gorantiwar (2005) where authors use "simulation – optimization techniques to allocate land and water resources optimally to different crops in a heterogeneous irrigation scheme with limited water under rotational water supply." (Simout and Gorantiwar, 2005:3).

two assumptions a market for a single good is independent from the rest of the economy. That is to say, changes in the dynamics of the specific market can be assumed to have no or limited effects on the rest of the economy.

In partial equilibrium models, supply and demand of the commodity under analysis is modeled in detail. Demand is generally found by maximizing some kind of objective function under pertinent constraints. For water markets, farmers are consumers while water authorities are suppliers. Thus the demand is be found by maximizing either the profits or surplus of producers. An alternative and frequently applied method is using a biophysical farm model to determine crop and time specific water demand. The second method requires more detailed data about yields, water requirements, irrigation areas and crops produced. Under the assumption of a functional relationship between inputs and output, the first method is rather simple and water demand can be obtained from the first order conditions of the optimization problem.

The supply side, on the other hand, is more difficult to model due to the uncertainty. Water supply is largely dependant on unpredictable weather conditions. One way to overcome this difficulty is to use outputs from hydrological models or historical data to determine the level of future availability. In this way water availability is made exogenous to the model variables and thus supply side shocks are given exogenously to the model. If the water availability can be assumed to be non-binding then uncertainty problem can be ignored. In this case, supply side can be determined in the same way as the other economic goods, i.e. by maximizing the profits of suppliers under an appropriate structural assumption (monopolistic, oligopolistic or competitive) about the water market. However, in most cases such an assumption is unrealistic and generally water supply functions are calibrated to historical data and effects of changes in water supply are analyzed exogenously.

3.1.2 Recent Work

Johansson *et. al.*, (2002) and Johansson (2005) give an extended survey of partial equilibrium models. The former covers the models until 1998 while the latter extends up to 2004. Jonhsson *et. al.* (2002) describes the general framework of partial equilibrium models and surveys the deviations of the models from the standard theoretical framework. Johnsson (2005), on the other hand, focus is on the taxonomy of the models according to their mathematical approaches and surveys the contribution of different models to different modeling methods. In this section we will give a survey of recent work aiming to model the water markets by using partial equilibrium analysis. We will focus on the contributions of these works to the theoretical framework of the models, as well as the details of their application.

Vaux and Howitt (1984) are cited as the pioneer work in implementation of partial equilibrium models in analyzing the water markets. They use a simple static non-linear specification of water markets to analyze the effects of regional water transfers. Following this pioneer work many similar models are applied to different parts of the world to analyze the effects and potentials of water markets. To count a few Gonzalez-Romero and Rubio (1993), Becker (1995) and Horbulyk and Lo (1998) can be given as examples (Garrido, 2004).

More complicated models have appeared in the literature as these models became solvable with the help of more able computer systems. Hamilton et al. (1989) and Michelson and Young (1993) have incorporated the institutional arrangements into their models. Weinberg et al. (1993), Dinar and Letey (1991) and Booker and Young (1994) introduced biophysical variables to the analysis of water markets. Dinar and Wolf (1994) used a game theory framework to simulate international water markets. Brill, Hochman, and Zilberman (1997) use a partial equilibrium model to analyze the performance of different pricing mechanisms.

Ray (2002) uses a partial equilibrium model to analyze the effect of different price levels of water on crop pattern throughout the year. His aim is to test the effects of increasing water prices and facilitating water markets. He concludes that “water price policy and/or a system of tradable water rights are not the most effective ways to increase irrigation efficiencies because water prices cannot be feasibly raised to the point where they can affect water demand and use.” (Ray, 2002:13)

Garrido (2004) criticizes the former programming models for ignoring the implications of droughts for the water markets, the transaction costs related to water trade, administrative units that play a key role in water markets, and the water market conditions that determine market equilibrium conditions. He has developed an integrated model to analyze the effects of water markets on Spanish agriculture. The modeling approach used by Garrido (2004) incorporates the geographical extent to which water markets need to be limited, the impact of transaction costs and the effect of asymmetric drought impacts affecting various water districts at the regional level. The model consists of three modules, a farm model that maximizes the farm surplus to determine the district-based water demand, an intra-district water markets model which maximizes the aggregate surplus of district to determine the water supply within the regions and an inter-district water market that determines the water exchanges among different regions.

Garrido (2004) applies the model to four districts in Guadalquilvir River Basin of Spain for five crops. The main conclusion of the simulations is that the number of participants and transactions in the water markets within the Spanish agricultural sector is likely to be low and thus granting the basin agency some responsibility in running and supervising market transactions is advisable. Further Garrido (2004) concludes that markets at the regional level are more effective and efficient. Different structures of irrigation districts such as crop pattern are at the heart of this efficiency gain and allow all parties participating in the trade to be better off.

One important problem about linear programming models has been their inability to calibrate to actual behavior by adding constraints or risk terms (Howitt, 2005). As an alternative positive mathematical programming (PMP) is offered by Howitt (1995). PMP method uses the actual data on crops and livestock to derive a quadratic cost function and thus calibrate the model without adding unrealistic constraints (Howitt, 2005). PMP approach assumes that unit cost of production rise as the amount of production increases. Thus the ratio of marginal costs to marginal revenues can be used to determine the optimal crop pattern. (Hall, 2001). Hence "*the PMP cost function calibrates exactly to observed values of production output, and factors usage. Second, PMP adds flexibility to the profit function by relaxing the restrictive linear cost assumption. A third advantage is that PMP does not require large datasets to as many inductive methods do, to provide enough price variability.*" (Medellin-Azaura, 2006:13).

PMP method has become the standard calibration method in recent work. Hall (2001) gives a partial equilibrium model based on positive mathematical programming (PMP) approach to develop a quadratic programming model of Murray-Darling Basin of Australia. The model developed by Hall (2001) is based on a linear programming model, namely Integrated Murray-Murrumbidgee Modeling System of the Australian Bureau of Agricultural and Resource Economics (ABARE). A detailed description of the model is given in Hall *et. al.*. (1994). Model of Hall *et. al.*. (1994) is a spatial equilibrium model that uses partial equilibrium model framework to link the region level models of water supply and demand while the irrigation regions included in the model covers half of the irrigated areas in Australia. Hall (2001) re-formulates the model by using the PMP approach and compares the results of linear model and quadratic model. He concludes that both models have superiorities to each other in different cases. Quadratic model performs better for simple cases while the linear model outruns the quadratic model when a more detailed modeling is needed.

Another example of PMP based partial equilibrium analysis is given by Marion *et. al* (2001). Their model uses an agricultural sector model, namely Statewide Water and Agricultural Production Model (SWAP) as an integrated part of the UC Davis Statewide Economic-Engineering Water Model (CALVIN). CALVIN is an economic-engineering optimization model. It attempts to represent the major storage and conveyance facilities which are inter-tied. The model gives estimates on groundwater supply, environmental water requirements, and agricultural and urban demands for water. Furthermore, the model is designed to suggest how this system might be operated based on economic criteria while meeting physical and environmental requirements.

CALVIN model uses SWAP model to estimate the economic valuation of urban and agricultural water demand. SWAP is built on the basis of a former partial equilibrium model of agriculture developed by Brown *et. al.* (1996), namely the Central Valley Production Model (CVPM). SWAP extends CVPM by covering more regions, using market prices instead of calibrated PMP costs, allowing yield to vary according to a quadratic production function, by fixing regional output prices and by making monthly analysis instead of a yearly one.

Like most of the partial equilibrium models, SWAP operates by maximizing economic returns subject to resource, production, and policy constraints under different supply conditions such as droughts. The objective function of SWAP is each region's total net returns from agricultural production with the appropriate production and resource constraints on water and land. The model can identify specific monthly water allocations assessing the willingness to pay of different agricultural water users for a reliable water supply by using shadow values as willingness-to-pay (Howitt *et. al.*, 2001).

A recent example of PMP based partial equilibrium models are given by He *et. al.*. (2006). They use static partial equilibrium models to analyze the effects of water policy in Morocco and Egypt. The models are developed by Doukkali (2002) and Siam (2001) for Morocco and Egypt, respectively. Both models maximize producer surplus from agricultural based commodities under various resource, technical, and policy constraints to find the water demand functions. He *et. al.* (2006) assumes that water supply is constant over time. They calibrate the base model with standard PMP. The crop productions are modeled using Leontieff type production functions. For Egypt 25 crops and 5 livestock products are covered by the model while for Morocco 50 crops and 7 livestock products are incorporated. Egyptian model consists of 8 regions while Moroccan model has 5 irrigation zones in 6 regions.

Using multi-model approaches have started in the last five years. These models use partial equilibrium models as a module to represent the economic side of the water allocation problem, while they rely on other types of models such as biophysical or hydrological models to introduce heterogeneity among farmers or uncertainty. Sunding *et al* (2002), for example, represents a multi-model approach. The economic part of the model, namely Californian Agricultural Resource Model (CARM), depends on partial equilibrium concept and *"provides various measures of economic impacts, including impacts of supply cuts on producers' surplus, producers' revenue, production, employment, and irrigated acreage"* (Sunding and Chong, 2006:242). The CARM objective function maximizes the sum of producer and consumer surplus from California agricultural crop production The model also takes uncertainty into account and derives differences between short–run and long-run. Heterogeneity among producers is incorporated into the model by introducing farms at different sizes. Lastly barriers to trade such as the prior appropriation system and riparian rights systems are also modeled (Sunding and Chong 2006). Sunding *et. al.* (2002) combine CARM with an agro-economic model, which supplies water productivity data, and with a detailed rationing model which measure the immediate impacts. (Sunding and Chong 2006).

Perret and Tauchain (2002) also use a multi-model approach to evaluate the effects of different irrigation pricing and distribution schemes in South Africa. Their model consists of five modules: Cost, farmer, irrigation scheme, crop and charging system modules. These modules interact to determine a number of micro-economic, socio-economic and technical variables to assess economic performance issues as well as hydraulic performance and water scarcity issues. The output is calculated by cost and crop modules Hence water demand is determined by these modules. Water supply on the other hand is determined by schemes module that lists different water availability options. Perret and Tauchain (2002) use this module to make simulations for Dingleydale - New Forest irrigation scheme.

Another example of multi-model approach is the WATERSIM Model developed by International Water Management Institute (IWMI) and International Food Policy Research Institute (IFPRI). WATERSIM models water and food production and the environmental issues at the global scale (Fraiture, 2007). It is an integrated model that combines different aspects of water management issue. The main focus of the model is on the effect of the changes in food demand on water demand at the global scale. There are two models in the

WATERSIM, one for the agricultural market and the other for the hydrological structure of the basins. The former determines the output prices and water demand while the latter determines the water supply.

Medellin-Azaura (2006) provides a partial equilibrium model focused on irrigation. He uses a multi-region and multi-crop model to value water in Mexicali Valley of Colarado River Delta in Mexico. The model is calibrated with PMP. The model uses a relatively less restrictive production function, namely CES function, and a high level of disaggregation. Water demand is found by maximizing the profits of different groups of farmers. The model addresses the heterogeneity in production not only by covering different crops but also by introducing different farm groups. Main findings are as follows: The ratio of shadow value of water obtained from the model to actual water fee is between 2.7 to 5.9 and low-value crops and poor-land quality agricultural regions are the likely sellers of water under extreme scarcity conditions.

Lastly, Tsur (2005) gives a rather interesting analysis of theoretical framework of partial equilibrium analysis of water markets. Tsur (2005) starts its analysis by stating that the demand for water is derived and it is closely related to seasonality as well as the quality. He uses both profit maximization and shadow price approaches to obtain the derived demand from a production function that takes the amount of water used in irrigation as an argument. Tsur (2005) introduces seasonality into his analysis by solving the input allocation model under sub-period water constraints. To construct the sub-period derived demands for water he finds the relationship between the shadow prices obtained from the constraints for every period and different levels of water use. He further introduces water quality issues by treating water at different quality as different inputs and obtaining different derived demands for each water type. Tsur (2005) does not give an application of his model. He uses graphical tools to analyze the effects of different pricing methods.

3.2 General Equilibrium Models

Partial equilibrium models cannot be used to make economy-wide inference and policy recommendations. However, in modeling the irrigation water, any change in environment, either policy or physical, is likely to affect the whole economy. One reason is the share of irrigation water in the total water use. The ratio is quite high as described above. Hence any shock is likely to have significant effects on macroeconomic variables. In order to analyze the macroeconomic effects of changes in water management policies a broader framework should be used. The computable general equilibrium models are developed to illuminate the relationship between macroeconomic effects of irrigation water management. In this section we will survey these models in detail and supply a detailed tabulation of these models.

3.2.1 Background

The attempts to model an economic system as a whole go back to the classical economists. Classical economists such as Adam Smith, David Ricardo or John Stuart Mill were intrinsically oriented towards a general equilibrium concept (Arrow, 2005). However, they have failed to formulate a general equilibrium system analytically. Walrass (1874) was first to recognize the need for as many equations as variables to define an equilibrium for a complete analysis of an economic system (Arrow, 2005). General equilibrium theory has become the standard theoretical framework for the analysis of the economy, especially after a series of papers from Arrow, Debreu, Kuhn and McKenzie published in 1950s (Arrow, 1958; Arrow and Debreu, 1954; Debreu, 1952, 1956 and 1959; Kuhn, 1956; McKenzei, 1954, 1955 and 1959). After these pioneering works, a vast of literature has appeared, and the theory of general equilibrium has been extensively developed by various researchers. This theoretical framework has evolved to applied models as early as 1930s. Frisch (1931 and 1933), Tinbergen (1937 and 1939) can be given as the examples of first applied general equilibrium models, though their approaches were different than that of today's researchers. In the post war period works of Klein (1952) and Klein and Goldberger (1955) were examples of short-term implementation of general equilibrium models. Scarf (1967) and Scarf and Hansen (1973) has developed the algorithms that facilitated most of the following applied work (Arrow, 2005).

The theoretical framework has evolved to computable general equilibrium models (CGE) (a.k.a. applied general equilibrium models (AGE)). Johansen (1960) is accepted as the first model in the literature that is consistent with the general equilibrium theory. Johansen's (1960) model is a disaggregated numerical model aimed at identifying the sectoral contributions to economic growth in Norway. The model had a simple structure with important differences from the CGE models developed later (Bergman, 1990). In mid-1970s the ORANI model was developed in the University of Melbourne within the context of IMPACT project. ORANI was aiming to model the sectoral allocation of capital and labor as well as the outputs (Bergman, 1990). ORANI is more detailed and improves the solution techniques offered in Johansen (1960) (Dixon, 1975).

The first major instances of CGE models, close to the current understanding of the term, were developed to analyze the developing countries, as a result of the work initiated by World Bank in the early 1970s (Bergman, 1990). Adelman and Robinson's (1978) model is the leading model in literature (de Maio et. al., 1999). The aim of the model was mainly concerned with the relationship between income distribution and economic growth. Adelman and Robinson (1978) solved the model directly in terms of the levels of endogenous variables. This is the most significant difference of their approach from the previous work (Bergman, 1982).

In 1980s and 1990s CGE modeling has been one of the most attractive fields of research for economists. Almost all topics in economics from financial issues to environmental policies have been the topic of CGE models. Berck et al. (1991) was first to analyze water policy in a CGE context. Their focus was on the impacts of water transfer from agriculture to other sectors in the San Jaoquin Valley, USA (Tiwari and Dinar, 2001) as well as giving a comparison of partial and general equilibrium models (Johansson *et. al.,* 2002). Following this work, a number of models are developed by various researchers.

Johansson (2000 and 2005) gives a detailed survey of the work done until 2000. In this section, we will make a survey of the recent work on computable general equilibrium models focusing on modeling water pricing and especially in water markets.[3]

3.2.2 Recent Work

In recent years, the increase in the consciousness of the international community about water issues is also reflected in the efforts spent to develop CGE models to analyze the effects of different policy options. In this part of our study, we will focus on the recent research that uses CGE models to analyze the water issues. A special emphasis is put on the pricing of irrigation water and water markets. The details about the production, consumption structures of the models are available in Table 2.

The early papers, namely Seung *et. al.* (2000) and Goodman (2000) came up with county level models aiming to go deep inside water policy. Seung et al. (2000) use a county level dynamic CGE model to estimate the welfare gains of reallocating water from agriculture to recreational use for the Stillwater National Wildlife Refuge in Nevada (Beritella, 2005b).

[3] We have excluded the papers that are somehow related to CGE modeling but do not present a CGE model. An example is Hassan (2003) which "traces the chain of value addition between primary production and final use" (Hassan, 2003) by using a quasi input-output approach to analyze the economy wide benefits of irrigation. He maps the chain of production linkages starting from the end or final product (e.g. refined sugar) to primary sector activity (e.g. cane plantation).

The model introduces a recreation demand module that is consistent with the general equilibrium framework. Water is modeled as a scarce source that should either be allocated to agriculture or recreational areas. Water is an input both for agricultural production and production of recreational areas. The utility function of the households includes recreation consumption as well as the other commodities. Hence, a “market for recreation” determines the price of “recreational areas” and these sectors compete for water resources. The simulation results conclude that transferring water from agriculture to recreation areas decreases regional GDP significantly.

Goodman (2000), on the other hand, uses a CGE model to shows that temporary water transfers cost less than establishment of new infrastructure for the Arkansas River Basin. Goodman (2000) models the water as a storable production factor. He introduces a separate module which supplies the water availability levels for the CGE model.

The water CGE literature also consists of excessively large models, too. An example is Peterson *et. al.*. (2004) who developed a 48 sector/20 region CGE model, based on the TERM model which is in turn based on ORANI model mentioned above. The model analyzes the effect of water trade on the effects of water scarcity and reports that allowing both intra- and interregional water trade among irrigators substantially lessens the impact of reducing water availability on gross regional product. The model is further refined by Dywer *et. al.*, (2005) extends the analysis of Peterson et al. (2004) to investigate the effects of expanding trade to include both irrigators and urban water users. They found that water trade compensates the losses from water reductions.

Tirado, *et. al.*. (2004) also illustrate the gains from voluntary water rights exchange mainly between the agriculture and urban sectors for Balearic Islands of Spain. With their 15 sector CGE model, they show that agricultural production is lower when there is a market for water rights than when there is not such a market. Tirado *et. al.* (2005) introduce Water Framework Directive to the same model, while Tirado *et. al.* (2006) analyze the effect of efficiency of irrigation on tourism sector and they conclude that water efficiency measures do not reduce economic pressures on water ecosystems.

Another ORANI based (to be precise the ORANI-G version of Harrison and Pearson (1996)) large scale CGE model is given by Letsoalo *et. al.* (2005). They test the triple dividend hypothesis which states that the taxes on environment can simultaneously stimulate economic growth, poverty reduction and environmental protection. The latter two are direct effect of an environmental tax while the former follows from the increase in the government revenue. By using a 65 sector/48 household CGE for South Africa they show that triple dividend is possible for water policy.

Beritella *et. al.* (2005a) develop GTAP-W, a large scale CGE model that extends GTAP Model of Hertel *et. al.* (1987). Their main contribution is the introduction of a water module to a very large trade model, namely GTAP. They relate water scarcity with international trade and analyze the possible effects of reductions in water availability on global trade. Their model consists of 17 sectors, 16 regions and 16 household types. In the model they consider both a non-market case and a market solution case. They conclude that welfare losses are substantially larger in the non-market situation. Beritella *et. al.* (2005b) introduce the tax policies to the model of Beritella *et. al.* (2005a). They conclude that water taxes reduce water use and lead to shifts in production, consumption, and international trade patterns. The countries that do not levy water taxes are also affected by the taxes levied by other countries. Lastly, effects of water tax on production and water tax on final consumption are different. Another extension to Beritella *et. al.* (2005a) is Beritella *et. al.*. (2006) who uses a the same CGE model to estimate the impacts of the Chinese North-South water transfer project on the economy of China and the rest of the world. They conclude that China will benefit from the project at the expense of the International trade and global GDP.

Another international trade model is offered by Kohn (2003). Kohn uses a Heckscher-Ohlin framework to illustrate the effects of international water trade. The focus is on the Middle East, which is assumed to be one of the important water conflict areas. They model water both as a produced good in which one of the countries have a comparative advantage and as an input used to produce the other good. Both countries are better off with international trade. Consequently he offers water markets as an alternative to warfare. Kohn (2003) utilized the Heckscher-Ohlin-Samuelson general equilibrium framework to examine the economic efficiency of international trade in water as a means to mitigate water scarcity when water is both an input and output among the trading countries (Bucconsufo, 2005; Beritella *et. al*, 2006).

Briand (2004) developed a static CGE model to estimate the effects of a water price policy on production and employment in Senegal (Velazquez, 2007). She models the drinking water as a consumer good and primary water as a production factor which is also a produced by government. Her modeling attempt turns out to be incomplete. However, she is the first to introduce the competition between irrigation and drinking water to a CGE model.

Finoff (2004) introduces a bio-economic model based on general equilibrium approach to analyze the effects of both stochastic changes in salinity levels and initial shock to population levels of species on the ecological and economic variables. The model is interesting since it is the first model that integrates biological aspects of water policy with a CGE framework. Agents in the model are energy maximizers. Water determines the salinization levels and biomass production in the model.

The Boccanfuso et al. (2005) extend the EXTER model of Decaluwé et al. (2001) which is an integrated multi-household (IMH) model. IMH models consist of large numbers of households by using household survey data to assess the effects of different policies on households in a detailed way. Boccanfuso *et. al.* (2005) is the first example of this approach focusing on water issues. They investigate the distributional impact of privatization of the water utility and isolate winners and losers of privatization in Senegal. They model water market with two water utilities that sell water to water suppliers with an exogenously determined price. They conclude that price changes have different general equilibrium effects and winners and losers depend on these effects.

Diao *et. al.* (2005) present a detailed intertemporal CGE model for Morocco. 88 activity types produce 49 final products in 20 regions. Their simulations show that water markets are likely to increase the agricultural output significantly in Morocco.

Roe *et. al.* (2005) represent a combined model that takes both micro and macro aspects of policy interventions for improving irrigation water allocation in a n analytical CGE framework for analyzing irrigation related issues in Morocco. The model allows for analysis of both top-down (trade reform) and bottom-up (farm water assignments and the possibility of water trading) linkages since it consists of both macro and micro aspects of the problem. The model consists of two modules, a farm level model and a macro level model. The farm level model solves the monthly irrigation water allocation for crops. Prices are exogenous for the farm model. On the other hand The CGE model accounts for the whole economy and prices are determined endogenously. CGE model consists of 82 production activities producing 44 commodities by employing 8 primary input in the agricultural sector. There are further 6 non-agricultural sectors spanning the rest of the economy. The country is separated into 20 perimeters. There are 5 types of households and the public sector at the demand side. International trade is differentiated among EU and rest of the world (Roe *et. al.*, 2005). Roe *et. al.* concludes that trade reform (top-bottom or macro to micro linkage) has a higher effect compared to water reform(bottom-up or micro to macro linkage). They also conclude that the sequencing of reforms is also important in determining the final effect.

Diao *et. al* (2008) is another extension of Dio *et. al.* (2005) and analyzes the groundwater resources in a general equilibrium framework. The structure of model is very similar to that of Dio *et. al.* (2005) except that ground water is modeled as an input for the agricultural production. The model also consists of urban water demand. The model concludes that grounds water is important in lessening the severity of the economic and climatic shocks.

Smajgl *et. al.* (2005) integrate theoretically agent-based modeling with a CGE model. They show that while CGE models allow the quantification of trade-offs between economic sectors, catchments and values, agent-based models make land-use decisions spatially explicit. The production side of the CGE is modeled in the standard way. However demand follows from the agent based model. In the demand side decisions cumulate in a preference based non-market utility function and a costs and revenues based economic payoff function. They conclude that integrated models are likely to perform better.

Lastly, Velazquez *et. al.* (2007) develop the models of Cardenete and Sancho (2003) and André *et. al.* (2005) to assess the impact of various of tax policies. They aim to analyze the effects of an increase in the price of the water delivered to the agriculture sector on the efficiency of the water consumption and the possible reallocation of water to the remaining sectors for Andalusia, Spain. Water is modeled as a production factor subject to taxes. The model is the first model that compares effects of different taxation schemes with the water market option. They conclude that although the tax policy does not yield significant water saving in the agricultural sector, a more efficient and more rational reallocation of water is achieved.

Table 2: Recent CGE Models related to water issues

Model	**Background**	**Further Analysis**	**Aim**	**Modeling approach**	**Production Function**	**Utility Function**
Seung *et. al.*, 2000			Comparing the effects of water transfer from agriculture to recreative areas	County level dynamic CGE model with a recreation demand module	Cobb-Douglas with fixed ratio intermediate inputs	CES
Goodman, 2000			Comparing the effects of water storage increase and water transfers	County level dynamic CGE model	CES	CES
Peterson *et. al.*, 2004	ORANI (Dixon *et. al.*. 1982) ;TERM Model (Horridge *et. al.*, 2003)	Dwyer, 2005;	the long run effects of trade under reductions in water availability and short run reductions based on observed allocations	Large Scale, standard CGE	Nested CES, 3 Level	demand follows a linear system of expenditure
Dwyer *et. al.*, 2005	extends the analysis of Peterson et al. (2004) to investigate the effects of expanding trade to include both irrigators and urban water users					
Tirado *et. al.*, 2004		Tirado *et. al.*. 2005 and 2006	analyze the welfare gains associated with an improvement in the allocation of water rights through voluntary water exchanges (mainly between the agriculture and urban sectors).		nested CES, 5 level for agriculture and 4 level for others	Stone-Geary function
Tirado *et. al.*, 2005	Tirado *et. al.*, (2004)	Tirado *et. al.*, 2006	provide information on water management options under Water Framework Directive.			

Model	Background	Further Analysis	Aim	Modeling approach	Production Function	Utility Function
Tirado *et. al.*, 2006	Tirado *et. al.*, (2004)	Tirado *et. al.*, 2006	explore the impact of increasing the technical efficiency of water use in the tourism sector.			
Kohn, 2003				Heckscher - Ohlin - Samuelson model	Cobb-Douglas	Simple multiplicative
Briand, 2004			To estimate the production and employment impacts of water policy pricing on the development of both formal and informal water distribution segments.	Static CGE	Nested CES, 3 Level for drinking water, 4 level for distribution, 5 level for agriculture	Linear System of Expenditure
Finoff, 2004			effects stochastic changes in salinity levels and an initial shock to species-population levels on the ecological and economic variables	Bioeconomic Model	Agents are energy maximizers	
Boccanfuso *et. al.*, 2005	extends Decaluwe (2001) by introducing water utilities		investigate on the distributional impact of privatization of the water utility and to isolate winners and losers of following privatization in Senegal	Integrated Multi-household	3 level nested CES	Cobb-Douglas
Diao *et. al.*, 2005	Diao and Roe 2000, 2003		economy-wide gains from the allocation of surface irrigation water decentralized mechanism for achieving this result in a spatially heterogeneous environment.	Intertemporal CGE	Available upon request	
Roe *et. al.*, 2005			Analyzing the effects of top-down and bottom-up reforms on irrigation water allocation.	Combines a CGE model with a farm model	Homogenous of degree one and non-increasing in inputs	

Model	Background	Further Analysis	Aim	Modeling approach	Production Function	Utility Function
Diao *et. al.* 2008	Roe et.al. (2005)		empirically evaluate the importance of conjunctive management in a general equilibrium setting	Extends Diaa et. al 2005 to to include surface and GW as two "intermediate sectors".		
Beritella *et. al.*, 2005a	GTAP (Hertel, 1997); GTAP-E (Burniaux and Truong, 2002)	Beritella *et. al.*, 2005b, 2006	role of water resources and water scarcity in the context of international trade	multi-region world CGE model	8 level, nested CES function under Armington assumption	3 level nested Cobb-Douglas under Armington assumption
Beritella *et. al.*, 2005b			to assess a series of water tax policies			
Beritella *et. al.*, 2006			to estimate the impacts of the North-South water transfer project on the economy of China and the rest of the world.			
Smajgl *et. al.*, 2005			Show that while CGEs allow the quantification of trade-offs between economic sectors, catchments and values, agent-based models make land-use decisions spatially explicit.	combines a Computable General Equilibrium (CGE) model and an agent based model (ABM) for integrated policy impact assessment.	Nested CES, 5 Levels	Supplied by agent based model. Decision making cumulates in a preference based non-market utility function and a costs and revenues based economic payoff function.

Letsoalo *et. al.*. 2005	ORANI-G (Harrison and Pearson, 1996)		to analyze the triple dividend of water consumption charges in South Africa: reduced water use, more rapid economic growth, and a more equal income distribution.	Static CGE	Nested CES with an overall Leontieff structure under Armington assumption	linear expenditure system under Armington assumption
Velazquez, 2007	Cardenete and Sancho, 2003; André *et. al.*, 2005		to analyze the effects of an increase in the price of the water delivered to the agriculture sector on the efficiency of the water consumption and the possible reallocation of water to the remaining sectors.	Standard Static CGE	Nested Cobb-Douglas, under Armington assumption	Cobb-Douglas

Table 2 (cont'd): Recent CGE Models related to water issues

Model	Investment	Factors of Production	Assumptions about Factors	Sectoral Detail	Household Detail	Coverage and Regional Detail
Seung *et. al.*, 2000	Endogenously determined dynamically by capital stock, sectoral profits and return rate	Labor, Capital, Land.	Labor: perfectly across regions; partially mobile across sectors Capital: immobile Investable Funds: Perfect	8 Sectors, 3 agricultural, 5 Other including finance,	3 Households: Low, middle, high income	1 Region, North Nevada, USA
Goodman, 2000	Determined by capital growth and depreciation	Land, Labor, Capital, Water	Labor: perfectly mobile, capital is sector specific land and water is usage specific,	4 Sectors, irrigated and non-irrigated agriculture, services and manufacturing	2 Rural and Urban	South-Eastern Colorado, USA
Peterson *et. al.*, 2004	Investment demand is determined exogenously	Land, Labor, Capital, Water	Labor is fully mobile within regions, partially mobile among regions, Land and capital are mobile at varying degrees	48 Sectors	1 Type	20 Regions in Sothern Murray Darling basin of Australia
Dwyer *et. al.*, 2005		net gains are greatest, and the costs to industries and regions are generally more dissipated, when trade is unconstrained. When regions with relatively low levels of water consumption face shortfalls in water availability and trade with regions that use large volumes of water they have little effect on traded prices and quantities.				
Tirado *et. al.*, 2004	Exogenous	Labor, capital, land, water and seawater	Labor is perfectly mobile Land and capital is mobile among agriculture sectors.	10 Sectors, 3 agricultural (irrigated and non-irrigated, livestock), 2 water sectors: traditional and desalinization	1 Type	Balearic Islands, Spain
Tirado *et. al.*, 2006						water efficiency measures do not reduce economic pressures on water ecosystems.

Model	Investment	Factors of Production	Assumptions about Factors	Sectoral Detail	Household Detail	Coverage and Regional Detail
Kohn, 2003	-	Labor, Water	-	2 products, water and non-water	-	Middle East two countries simulation
Briand, 2004	-	Primary water, Labor, Capital	-	3 Sectors: Drinking water production, distribution and agriculture	3 Types, Dakar, other urban, rural	Senegal, 3 regions
Finoff, 2004				5 Sectors including brine cyst harvesters, mining, agriculture, recreation, industry	1 type	Great Salt Lake ecosystem
Boccanfuso *et. al.*, 2005	Determined by agent savings	Qualified and Unqualified Labor, Capital, Water	Labor is mobile	18 Sectors	3,278 households modeled explicitly, no HH groups	Senegal, no regions
Diao *et. al.*, 2005		Rural Labor, Urban Labor, Capital, and Land	Labor is mobile within agriculture. Capital and Labor are mobile within regions among agricultural sectors, water is mobile within irrigation districts	88 activities: 82 Agricultural, 66 crops, 5 livestock, 11 processing 49 Products: 23 Agricultural	2 types: Rural and agricultural	Morocco, 20 Regions
Roe *et. al.*, 2005		Labor, Capital, Land		88 activities: 82 Agricultural, 66 crops, 5 livestock, 11 processing 49 Products: 23 Agricultural	5 Household types	Morocco, 20 Regions
Diao et. al., 2008				71 Agricultural; 66 in crop production, captured spatially as irrigated and non-irrigated, 33 crop production activities within the water irrigation authority perimeters, of which, 21 are irrigated crop production and 11 are rain-fed		Morocco, 21 Regions

Beritella *et. al.*, 2005a	Determined by savings and distributed to equalize the expected future rates of return for all regions	Capital, Labor , Land, Water	Capital and labor are perfectly mobile domestically, immobile internationally. Land and natural resources are sector specific, Water is mobile within agricultural sectors	17 Sectors 6 of which are related to agriculture includes a water distribution sector	17 Types, one for each region	16 Regions
Model	**Investment**	**Factors of Production**	**Assumptions about Factors**	**Sectoral Detail**	**Household Detail**	**Coverage and Regional Detail**
Beritella *et. al.*, 2005b	water taxes reduce water use, and lead to shifts in production, consumption, and international trade patterns. Countries that do not levy water taxes are affected by other countries' taxes. A water tax on production would have different effects than would a water tax on final cons.					
Beritella *et. al.*, 2006	Project would stimulate China's economy and increase welfare. The payback periods of different alternatives are between 1 and 3 years. Benefits of additional water supply are positive. If the water transferred is allocated to industry and households the benefits are halved.					
Smajgl *et. al.*, 2005						Great Barrier Reef Region of Australia
Letsoalo *et. al.*. 2005	Exogenous	Labor, Capital, Land	The capital is assumed to be fixed, while the rate of return on capital is allowed to change. Labor supply is perfectly elastic. The supply of land is also assumed to be inelastic.	27 Sectors, energy and water intensive sectors are further split into 39 sectors	12 Income, 4 ethnic groups	South Africa

Velazquez, 2007	Exogenous	Labor, capital, land, water	Capital supply is perfectly inelastic. In the labor market, there is a feedback between the real wage rate and the unemployment rate which represents rigidities in the labor market.	16 Sectors	1 Type	Andalusia, Spain

Table 2 (cont'd): Recent CGE Models related to water issues

Model	Time Dimension	Role of Water in the Model	International Trade	Contribution to literature	Main Findings
Seung *et. al.*, 2000	Dynamic: Goods market adjust in the short run via prices, factors market adjust in the long run by factor mobility	determines the land usage; very simple and indirect	Perfect trade with ROW, Armington Specification	1. Introduces integration of recreational demand with a CGE model and explicitly models alternative use of water	Using water for recreative areas instead of water decreases total welfare
Goodman, 2000	Dynamic: Goods market adjust in the short run via prices, factors market adjust in the long run by factor mobility	Production factor, can be stored, water availability is modeled separately	Perfect trade with ROW	Compares establishment of new infrastructure and reallocation	The benefits from increased transfers is higher than those from increased storage
Peterson *et. al.*, 2004	Static	Production factor, supply is fixed exogenously	Each regions is treated as a small open economy	Introduces one of the most detailed regional model to analyze water policies	allowing both intra- and interregional water trade among irrigators substantially lessens the impact of reducing water availability on gross regional product
Dwyer *et. al.*, 2005					
Tirado *et. al.*, 2004	Static	Production factor. Supply is constant	Small open economy, Armington Specification		agricultural production is lower when there is a market for water rights than when there is not such a market,

Model	Time Dimension	Role of Water in the Model	International Trade	Contribution to literature	Main Findings
Tirado *et. al.*, 2005					
Tirado *et. al.*, 2006					
Kohn, 2003	-	tradable good	Trade Model	Introduces Heckscher - Ohlin - Samuelson framework	both countries are better off when fresh water is internationally traded
Briand, 2004	Static	Drinking water modeled as consumer good, primary water is prod. factor and produced by government	Small open economy, Armington Specification	Introduces drinking water distribution as a separate sector, analyzes drinking water vs. irrigation	
Finoff, 2004	Static	Determines salinization and biomass	Small open economy,	First model that links biomass equilibrium to water policies	
Boccanfuso *et. al.*, 2005	Static	Intermediate input. Two water utilities selling water or water suppliers. Price of water is exogenous,	Small open economy, Armington Specification	First implication of Integrated Muti-Household approach to water modeling. Introduced stylized facts of the production behavior of the water sector	Price changes have important general eqb. effects Households are biggest loser from privatization. Rural households lose more.
Diao *et. al.*, 2005	Static	Production factor	Small open economy, Armington Specification		Water markets are likely to increase the agricultural output significantly.

Model	Time Dimension	Role of Water in the Model	International Trade	Contribution to literature	Main Findings
Roe *et. al.*, 2005	CGE is static, Farm level is intertemporal	Production factor	Small open economy	Takes macro-micro linkages into account. Combines a farm model with a CGE model	trade reform (top-bottmo or macro to micro linkage) has a higher effect compared to water reform(bottom-up or micro to macro linkage). They also conclude that the sequencing of reforms is also important in determining the final effect.
Diao *et. al.*, 2005	Static	Production factor	Small open economy	Frist to analyze groundwater in a CGE framework	GW has a critical role in mitigating the negative effects of these types of shocks
Beritella *et. al.*, 2005a	Static	Water resources are non-market goods, water is a production factor. water is combined with the value-added-energy nest and the intermediate inputs	Global trade model	Uses GTAP to analyze water policy, introduces water module for GTAP	Welfare losses are substantially larger in the non-market situation. Water-constrained agricultural producers lose, but unconstrained agricultural producers gain; industry gains as well. There are regional winners and losers from water supply constraints.
Beritella *et. al.*, 2005b					
Beritella *et. al.*, 2006					
Smajgl *et. al.*, 2005	Static	water cycle is approximated on a catchments level. Crucial indicators for an integrated assessment are remaining water volumes in streams and in aquifers.		Integrates a CGE model with an agent based which allows dynamics spatially explicit by introducing hydrological system and the ecological system.	Integration of agent based model with CGE gives more reliable results.
Letsoalo *et. al.*. 2005	Static	Production factor	Small open economy	Analyzes the relationship between poverty issues and water policies combines poverty reduction with environmental management	show that there can be a triple dividend of water policy, simultaneously reducing water scarcity, improving economic growth, and reducing poverty.

Velazquez, 2007	Static	A factor of which is subject to tax.	Small open economy trading with ROW, Rest of Spain and Europe,	Comparison of taxation reallocation	although the tax policy does not correspond to significant water saving in the agricultural sector, a more efficient and more rational reallocation of water is achieved.

4 Conclusion

The severity of the increase in the global environmental problems alerts for the likely water security in the 21st century. International community officially accepted scarcity of water only recently. Governments all over the world state that they are well aware of necessity of implementing appropriate measures to cope with this scarcity. Since water is one of the main production factors in agriculture and agriculture demands a very high proportion of water through out the world this alert also has serious implications for food security.

Efficiency in the allocation of water is offered as a remedy to increasing. However efficiency may require transfer of water usage rights from less efficient crops and regions to more efficient ones. At this point, equity has become a central concern in allocation since water is crucial for human life. Most frequently used institutional settings for allocating irrigation water are public administration and user based administrations. Water markets, which are advocated by many economists as a solution to efficient allocation problem, face difficulties during implementation. The allocation of water as an economic good is more complicated than the allocation of other economic goods because water possesses unique characteristics which in turn bring about externalities and market failures. Although markets have been considered to the most efficient mechanism to use in allocating scarce resources, water allocation has proved to be different. Water pricing is considered as the main policy tool that can be used to mitigate both quantity and quality dimensions of water scarcity and thus enhance efficient water use. The economic solution to the issue of water allocation may need some support in the form of institutions without which they may not work well.

Recent developments in the literature have shown that the issue of equity in the allocation of irrigation water is linked to poverty alleviation. Irrigation has been proven to be a poverty reduction tool for the 21st century.

The modeling of water in partial equilibrium models can either be from the supply side or demand side. Demand is generally found by maximizing some of objective function, which could be either the profits or surplus of producers under certain constraints. Biophysical farm models are another alternative that can be used to determine crop and time specific water demand, although they require more detailed data about yields, water requirements, irrigation areas and crops produced.

Modeling the supply side is more complex due to the uncertainty because water supply is largely dependant on unpredictable weather conditions. Outputs from hydrological models or historical data can therefore be used to determine the level of future availability. In this way water availability is made exogenous to the model variables and thus supply side shocks are given exogenously to the model. If the water availability can be assumed to be non-binding then uncertainty problem can be ignored.

Several policy issues have been addressed in Partial Equilibrium models. The widely researched areas have been the use of water markets and pricing in an effort to manage water scarcity. The results have been generally sector specific with water markets and pricing mechanisms bringing positive results in some areas and negative in others as discussed in section. Linear Programming models are arguably the most widely used Partial Equilibrium models in water management policy applications. Their problem however is their inability to calibrate to actual behavior by adding constraints or risk terms (Howitt, 2005).

Other techniques in Partial Equilibrium modeling have been discussed in the literature. These include Positive Mathematical Programming (PMP), which uses the actual data on crops and livestock to derive a quadratic cost function and thus calibrate the model without adding unrealistic constraints (Howitt, 2005). Multi-model approaches use partial equilibrium models as a module to represent the economic side of the water allocation problem, while they rely on other types of models such as biophysical or hydrological models to introduce heterogeneity among farmers or uncertainty. Their applications have been discussed in section 3. Tsur (2005) developed a theoretical framework of partial equilibrium analysis of water markets. There is however no application of this model.

CGE models on irrigation water management have different specifications of the production functions, utility functions, sectoral and household specifications, assumptions about factors and different time dimensions depending on the country or region under study. Recent CGE models have also emphasized on pricing of irrigation water and water markets just like the Partial Equilibrium models.

Seung *et. al.*. (2000) model water as an input in the agricultural sector and the recreational sector and conclude transferring water from agriculture to recreation areas decreases regional GDP significantly. Goodman (2000) on the other hand, shows that temporary water transfers cost less than establishment of new infrastructure. Water is modeled as a storable production factor. Diao *et. al.* (2005)'s simulations show that water markets are likely to increase the agricultural output significantly in Morocco.

Large water CGE models have been developed to address regional and international water trades for example Peterson *et. al.*. (2004)'s model analyzes the effect of water trade on the effects of water scarcity. They conclude that that allowing both intra- and interregional water trade among irrigators substantially lessens the impact of reducing water availability on gross regional product. Dywer *et. al.,* (2005) extends the analysis of Peterson et al. (2004) to investigate the effects of expanding trade to include both irrigators and urban water users. They found that water trade compensates the losses from water reductions. Beritella *et. al.*. (2005a) develop GTAP-W, a large scale CGE model that extends GTAP Model of Hertel *et. al.*. (1987). They conclude that welfare losses are substantially larger in the non-market situation. Beritella *et. al.*. (2005b) introduce the tax policies to the model of Beritella *et. al.*. (2005a). They conclude that water taxes reduce water use and lead to shifts in production, consumption, and international trade patterns. Countries that do not levy water taxes are also affected by the taxes levied by other countries. Beritella *et. al.*. (2006) uses and estimates the impacts of the Chinese North-South water transfer project on the economy of China and the rest of the world. They conclude that China will benefit from the project at the expense of the International trade and global GDP. Kohn (2003) uses a Heckscher-Ohlin framework to examine the economic efficiency of international trade in water as a means to mitigate water scarcity when water is both an input and output among the trading countries. Both countries are better off with international trade.

Tirado, *et al.*. (2004) illustrate the gains from voluntary water rights exchange between the agriculture and urban sectors. Agricultural production is lower when there is a market for water rights than when there is not such a market. Tirado *et. al.*. (2005) introduce Water Framework Directive to the same model, while Tirado *et. al.*. (2006) analyze the effect of efficiency of irrigation on tourism sector and they conclude that water efficiency measures do not reduce economic pressures on water ecosystems.

CGE models have also been used to analyze the impact of water policies on equity and poverty alleviation. Letsoalo *et. al.*. (2005) test the triple dividend hypothesis discussed in section 3.2. They concluded that there could be a triple dividend of water policy that would simultaneously reduce water scarcity, improve economic growth and reduce poverty. Velazquez *et. al.*. (2007) develop the models of Cardenete and Sancho (2003) and André *et. al.*. (2005) to assess the impact of various of water tax policies. They concluded that although the tax policy does not yield significant water saving in the agricultural sector, a more efficient and more rational reallocation of water is achieved.

Briand (2004) introduces the competition between irrigation and drinking water to a CGE model. Boccanfuso et al. (2005) concluded that price changes have different general equilibrium effects and winners and losers depend on these effects.

There has been limited research that combines both micro and macro aspects of policy interventions for improving irrigation water allocation. Roe *et. al.* (2005) use both top-down (trade reform) and bottom-up (farm water assignments and the possibility of water trading) linkages . They concluded that trade reform (top-bottom or macro to micro linkage) has a higher effect compared to water reform (bottom-up or micro to macro linkage). They also conclude that the sequencing of reforms is also important in determining the final effect.

There have been attempts in the literature to combine CGE models with other types of models in the analysis of water policies. Finoff (2004) introduces a bio-economic model based on general equilibrium approach. Smajgl *et. al* (2005) integrates theoretically agent-based modeling with a CGE model.

The complexity caused by the interrelationship between economic, cultural, social and political phenomena all related to water makes it impossible to write a prescription that will cure all problems about water issues. Better water management is certainly possible only with the introduction of better tools to measure and to plan water demand and supply. Economic models are attempts to fulfill this objective. In this paper we attempted to give a survey of recent work in economics literature and to shed light on the viewpoints of economists. Water has entered economic models only very recently. Thus, it may be fair to state that economics is in its infancy regarding water issues.

The models discussed in this survey have important deficiencies. Firstly, most of them lack the implementation of different pricing methods. As discussed earlier, the water policy is crucially dependent on the way water is priced. The second most important issue, is the fact that uncertainty due to climate change has not been incorporated into CGRE models yet this affects water availability. Uncertainty also has a significant effect on the behavior of economic agents. Thirdly, it is possible to incorporate market failures in the CGE models. As mentioned afore, market failures are at the core of the water policy since they are the basis of government intervention.

Consequently, there are still uncovered topics and regions. More effort needs to be devoted to research about economic modeling of water to produce policies that will pave the way for sustainable development.

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